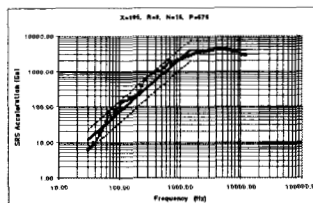
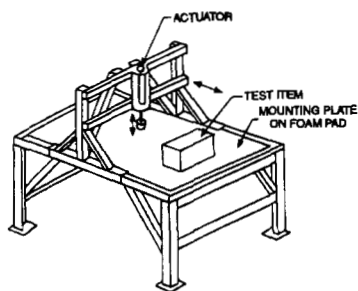


# Mechanical Impulse Pyro Shock (MIPS) Simulation



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Jet Propulsion Laboratory  
October, 1999



## Outline

- Introduction & Background
  - The Pyroshock Environment
  - The Shock Response Spectrum (SRS)
  - Typical Specification
- Test Techniques
  - Pyro Device Tests
  - Shaker Synthesis
  - Resonant Plate Methods
- MIPS Table Characteristics and Usage
  - MIPS Simulation
  - Characterization Efforts
  - JPL Tests
  - Future Plans
- Summary & Conclusions



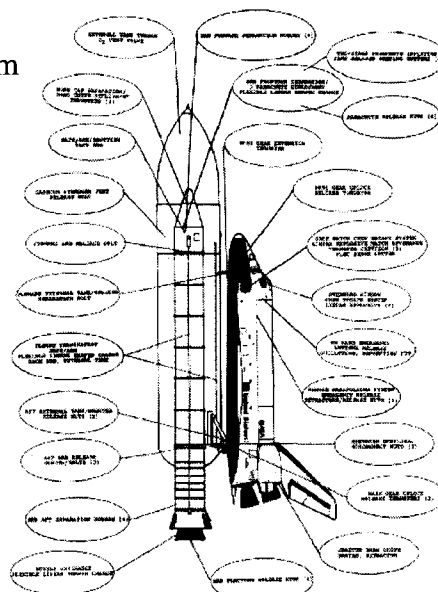
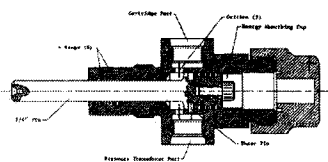
## Introduction & Background

- Pyrotechnic shock testing is part of the environmental qualification process.
- At JPL, this testing has traditionally been simulated on an electrodynamic shaker.
- Shaker overtests the low frequency vibration regime and undertests the higher frequencies.
- To enhance test fidelity, a resonant plate MIPS table was recently developed.
- This presentation discusses development of the table, its characterization and its usage in recent tests.



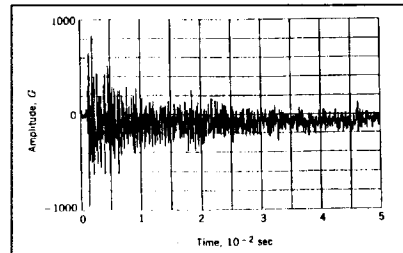
## The Pyroshock Environment

- Environment derives from initiation of pyrotechnic separation, safing and latching devices



## The Pyroshock Environment

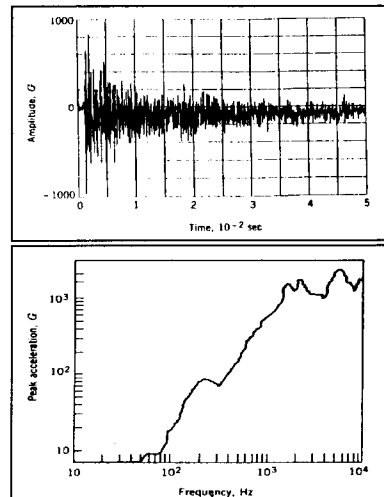
- Energy release from a pyro device produces tension/compression strain waves up to 40 kHz
- Results in a complicated acceleration versus time trace
- Characterized by high, oscillatory initial accelerations which decay rapidly ( $< 50$  ms)



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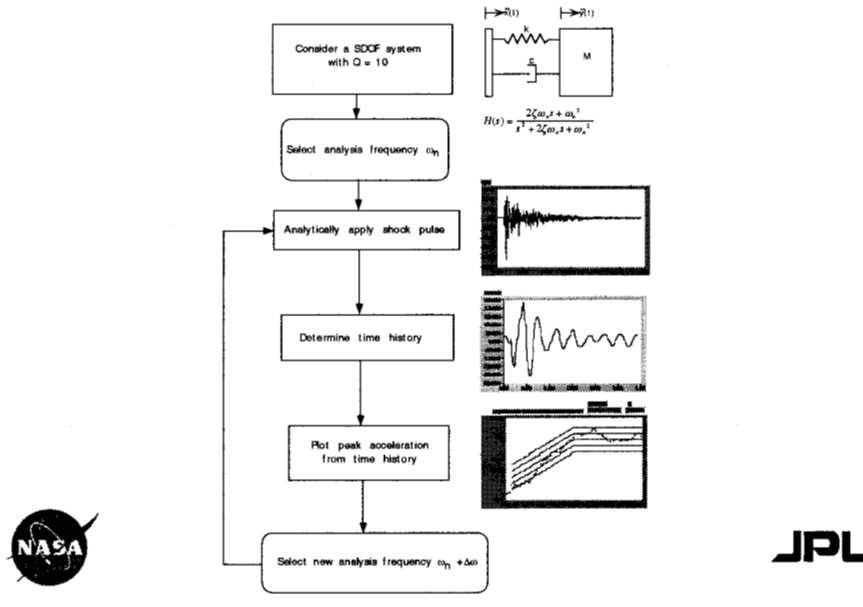
## Frequency Response to Pyroshock

- Rather than attempt to describe the input pulse, the structural frequency response is described instead
- The standard method for defining this frequency response is the Shock Response Spectrum (SRS)



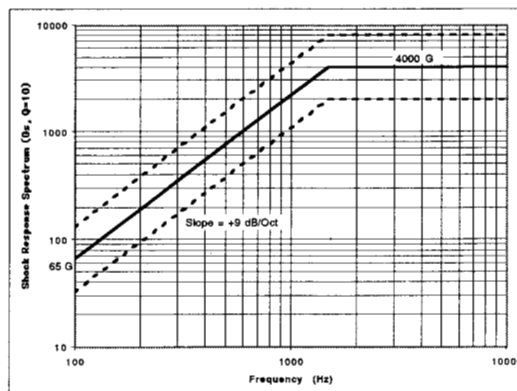
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## The Shock Response Spectrum (SRS)



## Typical Pyroshock Specification

- Shows, at each frequency, the peak response of a SDOF system to released shock energy
- Stated in terms of SRS ( $Q=10$ )



## Test Techniques

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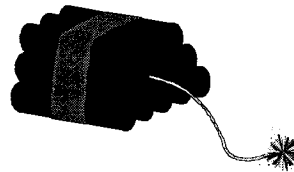
- Pyrotechnic Device Tests
- Shaker Synthesis
- Resonant Plate Methods
  - MIPS Simulation



## Pyrotechnic Device Tests

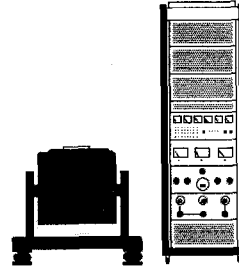
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- Actual explosive ordnance are used to reproduce the anticipated shock spectrum.
- Highly accurate if “real” structure is simulated.
- Costly
  - Requires special facilities
  - Expendable fixturing
- Hazardous



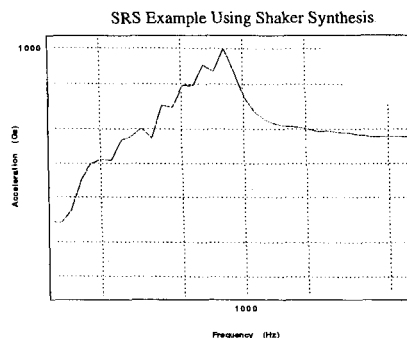
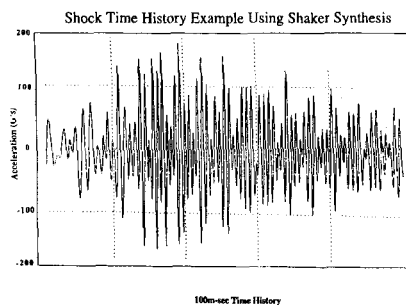
## Shaker Synthesis

- Acceleration transient is synthesized on an electrodynamic shaker
- Commonly used & cheap
- Problems:
  - Mechanical shaker is an inherent low pass filter
  - Production of high frequency energy difficult
  - Result is overtest at low and undertest at high frequencies
  - Shock synthesis limits shaker life
  - Difficult to conduct on large components
  - Easy to “cheat” time domain input to obtain an “official looking” SRS



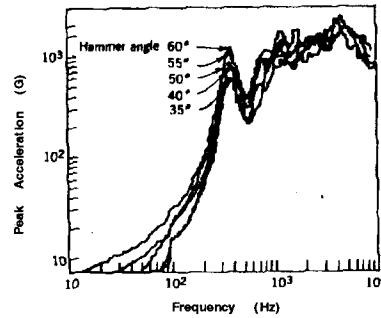
## “Cheating” via Shaker Synthesis

- SRS specifications are not unique; they can be met with an infinite variety of time domain acceleration traces.
- Example below shows how a non-shock-like time history can generate a shock-like SRS.



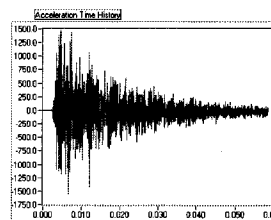
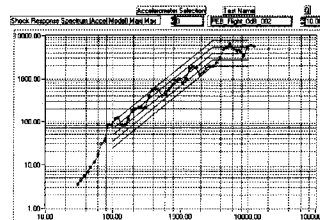
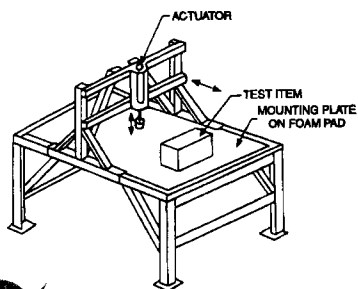
## Resonant Plate Methods

- Test article mounted to metal plate, suspended on bungies
- Plate hit with pendulum
- High frequency ringing simulates pyro shock
- Problem: difficult to tailor the response spectrum



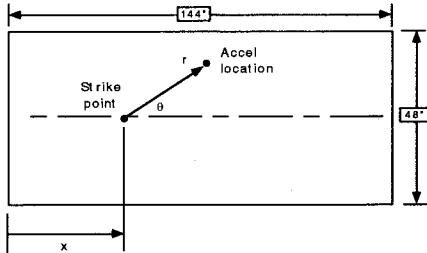
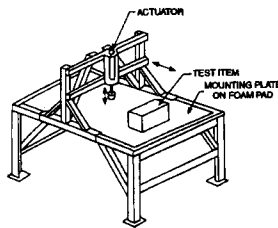
## The Mechanical Impulse Pyro Shock (MIPS) Simulator

- Aluminum plate (resting on foam or plywood pad) is excited into resonance
- Shock is generated by a pneumatic actuator on a moveable bridge
- Interchangeable impactor heads (lead, aluminum, steel) alter pulse duration
- Produces high frequency energy
- Extremely repeatable



## MIPS Table Characterization - Problem

- Determine strike position, damping, cylinder pressure and accelerometer position required to produce a customer-defined Shock Response Spectrum.



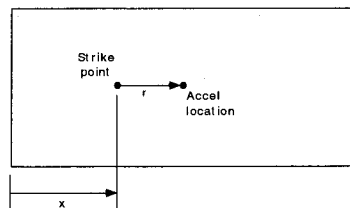
Symbol	Parameter
P	Pressure (psi)
N	Number of sheets
x	Linear position (inches)
r	Distance from strike point to accel & test article (inches)
$\theta$	Angle from strike point to accel & test article (radians)
m	Mass of test article (kg)
HT	Head type
a	SRS acceleration at frequency $f$ (g)
f	Analysis frequency (Hz)



## MIPS Table Characterization - Approach

- Take initial data set excluding mass of test article, impact head material and accelerometer angular position
- Total of 81 permutations on P, N, x and r

Parameter	Values
Pressure (P)	250, 575 and 900 psi
Damping (N)	0, 15 and 30 sheets
Strike pos'n (x)	72, 105 and 132 inches from table edge
Accel pos'n (r)	9, 16.5 and 24 inches from strike point
Angle ( $\theta$ )	0
Test Article mass (m)	0
Head Type (HT)	Steel



## MIPS Table Characterization - Approach (cont'd)

Tough!

- Develop a math model using:
  - Buckingham Pi theorem
  - Response surface techniques
  - Levenberg-Marquardt nonlinear regression
  - TableCurve 3D data fit software

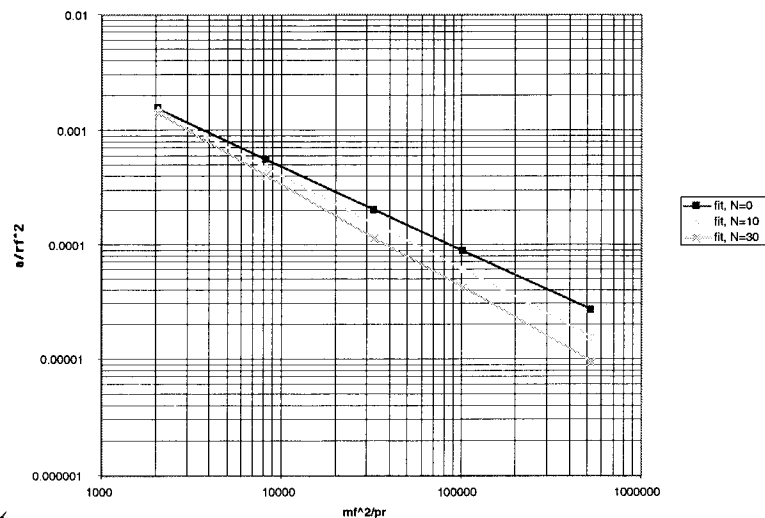
Success!

- Develop a software tool to correlate a demand shock spectrum with stored MIPS spectra



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## MIPS Table Characterization - Buckingham Pi Solution



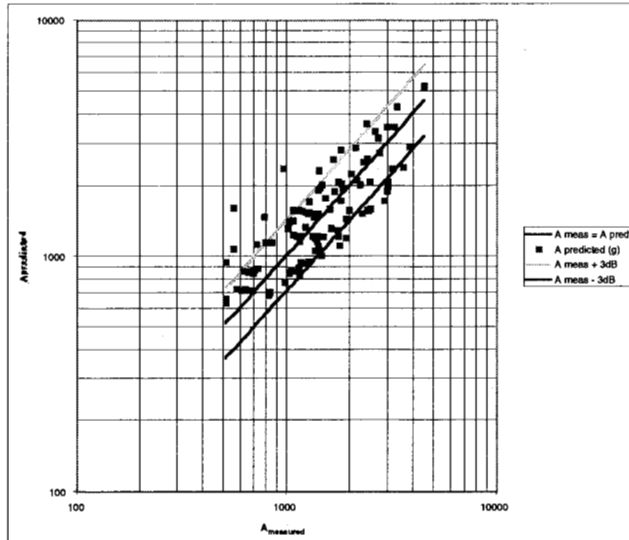
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## MIPS Table Characterization - Buckingham Pi Solution

$$\frac{a}{rf^2} = b \left( \frac{mf^2}{Pr} \right)^s$$

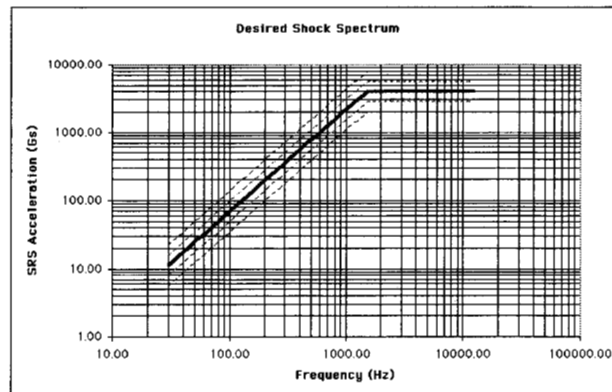
$$b = \frac{x}{4} \left\{ 10^{[0.025N + 0.2324]} \right\} + \left( 1 - \frac{x}{4} \right) 10^{[0.0243N - 0.1548]}$$

$$s = -x[0.000248N + 0.02693] - [0.00727N + 0.7782]$$



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## MIPS Spectrum Tool - Front End I/F



Input

Correlate

Print

Show +/- 3dB limits

Show +/- 6dB limits

Hide +/- 3dB limits

Hide +/- 6dB limits



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## MIPS Spectrum Tool - Input Screen

	A	B	C	D
1	Input Data			
2	Point	Frequency (Hz)	Input	Units
3	0	30	9	dB/10ct
4	1	1500	4000	Gs
5	2	2000	4000	Gs
6	3	5000	4000	Gs
7	4	10000	4000	Gs
8	5	15000	4000	Gs

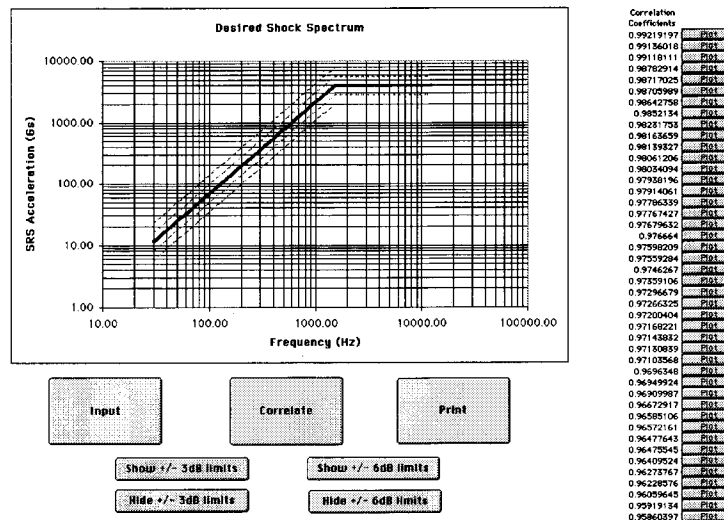
Done

3	0	30	11.54	Gs
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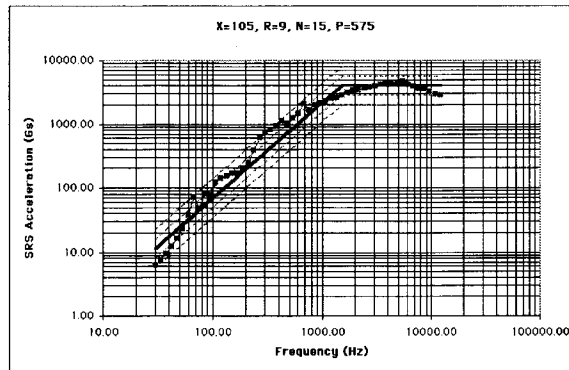
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## MIPS Spectrum Tool - Data Correlation



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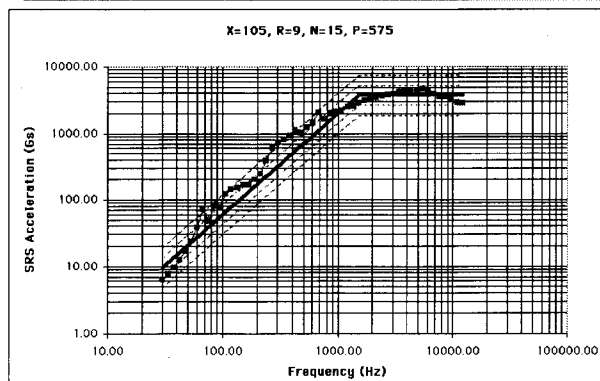
## MIPS Spectrum Tool - Best Fit



Correlation Coefficients	
0.99219197	Pd1
0.99136016	Pd1
0.99118111	Pd1
0.98782914	Pd1
0.98717025	Pd1
0.98705989	Pd1
0.98642758	Pd1
0.9852134	Pd1
0.9821703	Pd1
0.98163639	Pd1
0.98139327	Pd1
0.98061206	Pd1
0.98034094	Pd1
0.97958196	Pd1
0.97914061	Pd1
0.97786539	Pd1
0.97767427	Pd1
0.97679632	Pd1
0.976664	Pd1
0.97596205	Pd1
0.97592984	Pd1
0.9746267	Pd1
0.97399106	Pd1
0.97296679	Pd1
0.97264323	Pd1
0.97200404	Pd1
0.97166221	Pd1
0.97143882	Pd1
0.97130839	Pd1
0.97103968	Pd1
0.9696349	Pd1
0.96949524	Pd1
0.96909987	Pd1
0.9672911	Pd1
0.96585106	Pd1
0.96572161	Pd1
0.96477643	Pd1
0.96475543	Pd1
0.96409524	Pd1
0.96273767	Pd1
0.96228576	Pd1
0.96096446	Pd1
0.95919134	Pd1
0.95860397	Pd1



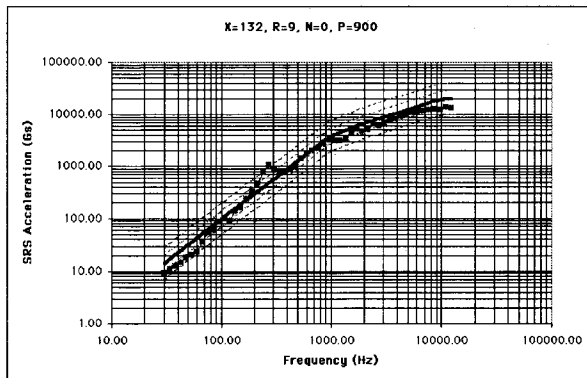
## New Millennium DS1 - Shock Zone 1



Correlation Coefficients	
0.99290406	Pd1
0.99179203	Pd1
0.98999828	Pd1
0.98981926	Pd1
0.98989173	Pd1
0.98831772	Pd1
0.98708401	Pd1
0.9861966	Pd1
0.98462397	Pd1
0.98432296	Pd1
0.98254933	Pd1
0.98189637	Pd1
0.98199316	Pd1
0.98133019	Pd1
0.98114473	Pd1
0.98005625	Pd1
0.97967741	Pd1
0.97947098	Pd1
0.97816123	Pd1
0.97799653	Pd1
0.97788897	Pd1
0.97768818	Pd1
0.97696984	Pd1
0.97677312	Pd1
0.97233767	Pd1
0.97201862	Pd1
0.97189218	Pd1
0.97186821	Pd1
0.97154353	Pd1
0.97140979	Pd1
0.97106086	Pd1
0.97103049	Pd1
0.97100916	Pd1
0.97085103	Pd1
0.9698168	Pd1
0.96804469	Pd1
0.96732571	Pd1
0.96689906	Pd1
0.96598881	Pd1
0.96596006	Pd1
0.96559706	Pd1
0.96546897	Pd1
0.96449421	Pd1



## Cassini - Shock Zone 5



Input

Correlate

Print

Show +/- 3dB limits

Show +/- 6dB limits

Hide +/- 3dB limits

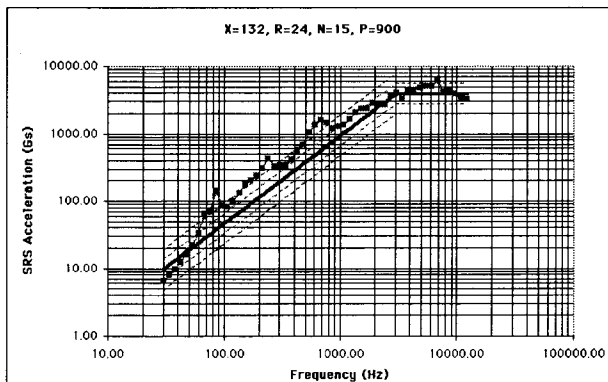
Hide +/- 6dB limits

Correlation Coefficients

0.98548197	Pst
0.98545665	Pst
0.9820443	Pst
0.97523247	Pst
0.95900166	Pst
0.94570317	Pst
0.94345067	Pst
0.93409047	Pst
0.92844733	Pst
0.92788101	Pst
0.92784391	Pst
0.92458153	Pst
0.92073321	Pst
0.90987712	Pst
0.90967283	Pst
0.90015908	Pst
0.8964033	Pst
0.88196382	Pst
0.8644327	Pst
0.85606496	Pst
0.84921052	Pst
0.84405409	Pst
0.83620037	Pst
0.83182897	Pst
0.83111597	Pst
0.82827619	Pst
0.81869716	Pst
0.80504822	Pst
0.80014361	Pst
0.79448657	Pst
0.78599728	Pst
0.78018213	Pst
0.77690185	Pst
0.77510271	Pst
0.75442146	Pst
0.75264217	Pst
0.74779212	Pst
0.72794603	Pst
0.72755947	Pst
0.72491084	Pst
0.72017192	Pst
0.71919678	Pst
0.71481499	Pst
0.70301527	Pst



## Mars '01 Shock Spectrum



Input

Correlate

Print

Show +/- 3dB limits

Show +/- 6dB limits

Hide +/- 3dB limits

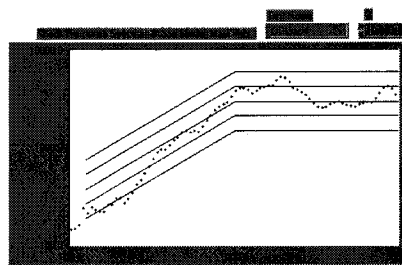
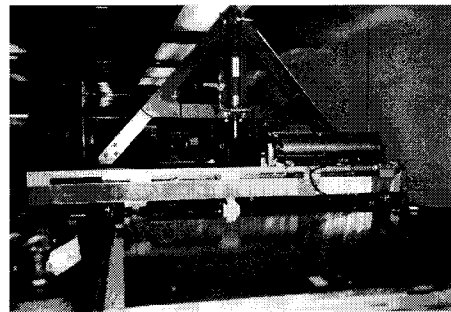
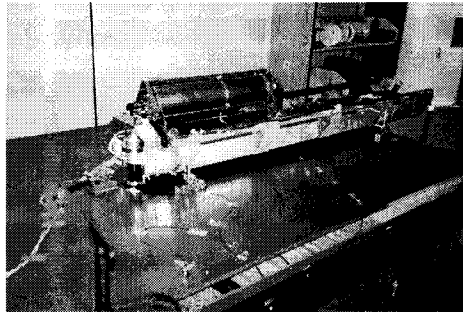
Hide +/- 6dB limits

Correlation Coefficients

0.9895325	Pst
0.98862622	Pst
0.98861397	Pst
0.98747537	Pst
0.98692077	Pst
0.98632123	Pst
0.98560636	Pst
0.98524642	Pst
0.98510439	Pst
0.9838907	Pst
0.98278685	Pst
0.98178728	Pst
0.98025999	Pst
0.98039005	Pst
0.97893787	Pst
0.97632174	Pst
0.97581543	Pst
0.97495878	Pst
0.97361527	Pst
0.97347468	Pst
0.97238749	Pst
0.97228514	Pst
0.97173875	Pst
0.97144849	Pst
0.97017076	Pst
0.96911432	Pst
0.96851386	Pst
0.9681644	Pst
0.96718622	Pst
0.96599568	Pst
0.9626941	Pst
0.96200236	Pst
0.96171387	Pst
0.9609705	Pst
0.96014146	Pst
0.95983457	Pst
0.95951952	Pst
0.9583974	Pst
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0.95517704	Pst

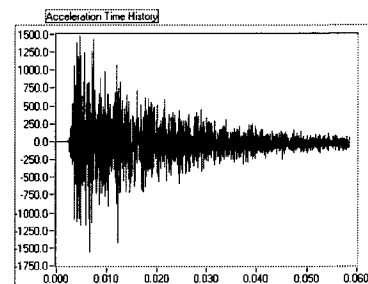
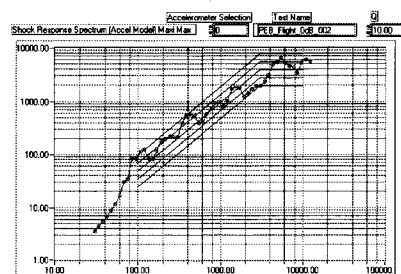
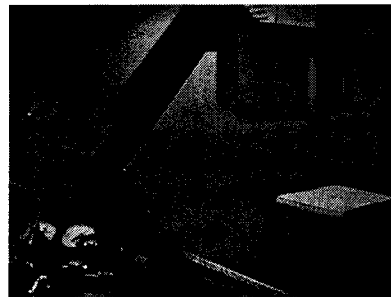


## MIPS Simulator - Optical Delay Line Test



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## MIPS Simulator - Mars '01 PEB Test



## MIPS Table - Future Plans

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- Deliver a MIPS “User Guidebook”
  - Explain MIPS theory
  - Give table operating procedures
  - Explain background and usage of spectrum tool
- Include effects of:
  - Test article mass
  - Changes in impact head material
- Include angular position in accelerometer standoff
- Produce an improved analytical model



## Summary & Conclusions

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- MIPS simulation produces high fidelity pyroshock spectra
- Software characterization tool works well
- User guidebook is in the works
- Need to include test article mass, head material change and accelerometer angle in future work
- More work needed on analytical model
- Additional MIPS tests planned later this calendar year:  
Mars '01, X2000 hardware



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